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(54) Method and apparatus for purging a NOx trap

(57) An engine control apparatus comprises
a NO_x trap (32) located in the exhaust passage of a multi-cylinder engine (18), the NO_x trap (32) having an oxygen storage capacity;
a catalytic converter (26) located in said exhaust passage upstream of said NO_x trap (32), catalytic converter (26) having a lower oxygen storage capacity than said NO_x trap (32); and
a computer (20) programmed to:

estimate when the trap (32) should be purged, and decrease the A/F supplied to the engine (18) to purge said NO_x trap.

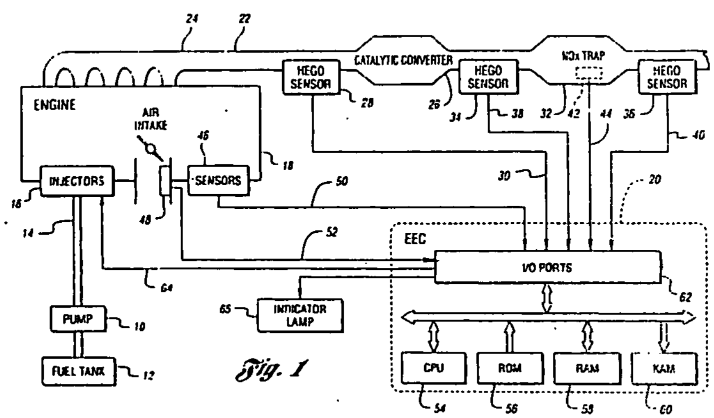

Fig. 1

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Description

[0001] This invention relates to exhaust after-treatment and, more particularly, to a method and apparatus for purging a NO_x trap.

[0002] Lean burn engines usually operate at an air/fuel ratio (A/F) ≥ 18 to obtain improved fuel economy. However, the usual three-way catalyst (TWC) is most efficient at approximately stoichiometry, (A/F=14.65). Accordingly, it has been proposed to locate a NO_x trap downstream of the TWC to store NO_x during lean A/F operation and subsequently converting the NO_x to N_2 and O_2 by operating the engine at a rich A/F. This NO_x conversion occurs within an optimum temperature window of approximately 300°C to 400°C. The trap is preferably located underbody so that during hard, wide-open throttle (WOT) driving, the trap temperature does not exceed 800°C. The temperature of the three-way catalyst should not exceed approximately 1000°C.

[0003] Reference is made to European Patent Application 98306144.1 (Publication No. 0 899 430) which contains the same disclosure as the present application but claims a method of engine operation comprising a sequence of the following steps estimating the amount of contaminant accumulated in a NO_x trap located in the exhaust path of the engine; varying the A/F of the mixture supplied to the cylinders of the engine when the estimated amount of contaminant reaches a threshold amount to raise the temperature of the trap to a predetermined temperature sufficient to purge the NO_x trap of contaminants; purging the trap of contaminant when said predetermined temperature is reached; and terminating the purging of said trap when a predetermined purge criteria is met; characterised in that the step of varying the A/F of the mixture supplied to the cylinders of the engine comprises supplying the engine cylinders with a mixture having an A/F that alternates in time between a rich value and a lean value, the frequency and the amplitude of the deviations of the A/F from its mean value being such as to heat the NO_x trap to said predetermined temperature.

[0004] According to the present invention, there is provided an engine control apparatus comprising:

a NO_x trap located in the exhaust passage of a multi-cylinder engine, the NO_x trap having an oxygen storage capacity;
a catalytic converter located in said exhaust passage upstream of said NO_x trap, the catalytic converter having a lower oxygen storage capacity than said NO_x trap; and
a computer programmed to:

estimate when the trap should be purged, and
decrease the A/F supplied to the engine to purge said NO_x trap.

[0005] The invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 shows a block diagram of the trap desulphation system of the present invention;
Figure 2 is a graph of NO_x trap midbed temperature vs. the A/F amplitude vs. the A/F modulation period;
Figure 3 is a graph comparing NO_x trap midbed temperature vs. A/F amplitude with and without a three way catalyst in the exhaust path; and
Figures 4a and 4b are a flowchart of the trap desulphation method of the present invention.

[0006] Referring now to the drawings and initially to Figure 1, a block diagram of the present invention is shown. A fuel pump 10 pumps fuel from a tank 12 through a fuel line 14 to a set of injectors 16 which inject fuel into an internal combustion engine 18. The fuel injectors 16 are of conventional design and are positioned to inject fuel into their associated cylinder in precise quantities as determined by an electronic engine controller (EEC) 20. The fuel tank 12 contains liquid fuels, such as gasoline, methanol or a combination of fuel types.

[0007] An exhaust system 22, comprising one or more exhaust pipes and an exhaust flange seen at 24, transports exhaust gas produced from combustion of an air/fuel mixture in the engine to a conventional three-way catalytic converter (TWC) 26. The converter 26 contains catalyst material that chemically alters the exhaust gas to generate a catalysed exhaust gas. A heated exhaust gas oxygen (HEGO) sensor 28, detects the oxygen content of the exhaust gas generated by the engine 18, and transmits a representative signal over conductor 30 to the EEC 20. A NO_x trap 32 is located downstream of the converter 26 for trapping nitric oxide contained in the exhaust gas exiting the converter. A HEGO sensor 34 detects the oxygen content of the exhaust gas ~~upstream of the trap 32 while a HEGO sensor 36~~ detects the oxygen content of the exhaust gas downstream of the trap 32. The sensor 34 and 36 transmits signals over respective conductors 38 and 40 to the EEC 20. The NO_x trap 32 contains a temperature sensor 42 for measuring the midbed temperature which is provided to the EEC 20 over the conductor 44.

[0008] Alternatively, the midbed temperature may be estimated using a computer model.

[0009] Still other sensors, indicated generally at 46, provide additional information about engine performance to the

EEC 20, such as crankshaft position, angular velocity, throttle position, air temperature, etc. over conductor 50. The information from these sensors is used by the EEC 20 to control engine operation.

[0010] A mass air flow sensor 48 positioned at the air intake of engine 18 detects the amount of air inducted into an induction system of the engine and supplies an air flow signal over conductor 52 to the EEC 20. The air flow signal is utilised by EEC 20 to calculate a value that is indicative of the air mass flowing into the induction system.

[0011] The EEC 20 comprises a microcomputer including a central processor unit (CPU) 54, read only memory (ROM) 56 for storing control programs, random access memory (RAM) 58, for temporary data storage which may also be used for counters or timers, and keep-alive memory (KAM) 60 for storing learned values. Data is input and output over I/O ports generally indicated at 62, and communicated internally over a conventional data bus generally indicated at 64. The EEC 20 transmits a fuel injector signal to the injectors 16 via signal line 64. The fuel injector signal is varied over time by EEC 20 to maintain an air/fuel ratio determined by the EEC 20. An indicator lamp generally indicated at 66 is controlled by the EEC 20 to provide an indication of the condition of the NO_x trap 32 as determined by input data from the various sensors.

[0012] The program stored in ROM 58 implements an air/fuel. strategy where the engine is operated in lean mode or relatively high air to fuel ratio (A/F) for fuel economy under certain engine speed/load conditions. The TWC 26 operates at temperatures between 400°C and 1000°C for good efficiency and durability. The trap 32 operates in a window of 300°C to 400°C for good efficiency. If the fuel contains sulphur, sulphur tends to deposit in the trap, reducing its NO_x trapping efficiency and the ultimate conversion of NO_x to harmless nitrogen and oxygen within the trap. To purge the trap of sulphur, the trap must be heated to approximately 650°C. The purging operation typically requires 3 to 10 minutes at that temperature. During the lean mode, NO_x and SO_x accumulates in the NO_x trap. After substantially total sorption of the trap 32, the purging operation is carried out. After purging is completed the EEC usually returns to the lean mode of operation.

[0013] An exotherm of sufficient temperature rise is created in the trap 16 by modulation of the air-fuel mixture supplied to the engine cylinders through manipulation of the fuel injection quantities.

Table 1.

A/F Modulation Schedule																				
Stroke Cyl. 1	P	E	I	C	P	E	I	C	P	E	I	C	P	E	I	C	P	E	I	C
Cylinder 1	L	L	L	L	L	L	L	L	L	L	R	R	R	R	R	R	R	R	R	R
Cylinder 2	L	L	L	L	L	L	L	L	L	L	R	R	R	R	R	R	R	R	R	R
Cylinder 3	L	L	L	L	L	L	L	L	L	L	R	R	R	R	R	R	R	R	R	R
Cylinder 4	L	L	L	L	L	L	L	L	L	L	R	R	R	R	R	R	R	R	R	R
	<- - - - - - - - τ - - - - - - - - ->																			

[0014] Table 1 shows an example of a typical fuel injection pattern. For this pattern, all cylinders are operated lean (L) for 10 events and all cylinders are operated rich (R) for 10 events. The resulting modulation period is equal to 20 engine events. The period can be chosen to be a fixed number of events or a fixed time τ. For the latter case, the number of engine events varies with engine speed (rpm). Typical periods may vary from two engine events to several seconds. The engine events are designated at P for power stroke, E for exhaust stroke, I for intake stroke, and C for compression stroke. The engine events are referenced to TDC of cylinder number 1. The engine cylinder firing order is 1342.

[0015] Figures 2 and 3 demonstrate the attainment of midterm temperatures near 700° C within a lean NO_x trap through the application of the A/F modulation technique. These results were obtained using a laboratory pulse flame combustor where the inlet gas to the NO_x trap was preheated and controlled to 350° C. In both instances the A/F amplitude was varied between 0 and either 4 or 5 A/F units. For example, given a mean A/F of 14.5 (i.e., stoichiometry), an A/F amplitude of 4 units results in modulation between a lean A/F of 18.5 and a rich A/F of 10.5. Figure 2 illustrates the effect of A/F modulation amplitude and frequency on the exothermic temperature rise for a NO_x trap with no TWC located upstream from the trap. The highest rate of exothermic temperature rise was obtained with a modulation period of 1 second (τ=1.0). For a fixed A/F modulation period of 1 second, Figure 3 compares the case where there is no TWC upstream of the NO_x trap (graph A) to the case where a TWC and NO_x trap are placed in series (graph B). Without an upstream TWC, a NO_x midbed temperature of approximately 650° C is achieved for an A/F modulation amplitude of 2. With a TWC positioned upstream of the NO_x trap, an A/F modulation amplitude of 4.5 was required in order to raise the NO_x trap temperature to the desox (desulphation) temperature of 650° C. With the TWC positioned upstream of the NO_x trap, larger A/F amplitudes are required in order to exceed the oxygen storage capacity of the TWC and hence create lean and rich breakthrough into the NO_x trap. By judicious selection of the A/F amplitude and frequency, a portion of the exothermic temperature rise can be made to take place directly in the NO_x trap rather than totally in the upstream TWC. Although symmetric modulation was discussed above, asymmetric modulation, in which the half-periods of the lean and rich modulation events are different, may be used in generating the exotherm.

[0016] The system design forces HC, CO, AND O_2 breakthrough in the TWC. This permits chemical energy to be transported from the exit of the TWC, through the exhaust pipe, to the trap. The design objective for the trap is to promote chemical reactions of HC, CO, and O_2, which create an exotherm in the trap and raise its temperature. Preferably, breakthrough in the trap is minimised. The system design meets the following conditions: The combination of engine mass air flow and A/F modulation saturates the oxygen storage capacity of the TWC and approximately saturates the oxygen storage capacity of the trap. The rate at which the TWC and trap O_2 storage sites fill with O_2 is proportional to the product of engine mass air flow and the O_2 concentration. For lean A/F, the O_2 concentration is proportional to the difference between the exhaust A/F ratio and the stoichiometric A/F (typically 14.5).

[0017] The A/F ratio modulation period τ may be chosen to be large with respect to the time necessary to fill the O_2 storage sites in the TWC and small with respect to the time necessary to fill the O_2 storage sites in the trap. The filling time is inversely proportional to the engine mass flow rate and the O_2 concentration. The latter is proportional to the A/F ratio modulation span.

[0018] The oxygen storage capacity of the TWC and trap can be varied through well known methods. The concentration of cerium in the washcoat can be changed and the physical size of the TWC and trap can be changed. Increasing both parameters tends to increase the oxygen storage. The oxygen storage capacity of the trap (C2) is significantly greater than the oxygen storage capacity of the TWC (C1). C1 is minimised so that most of the exotherm occurs in the trap rather than the TWC.

[0019] During the desulphation process, the A/F ratio and spark advance are controlled. The A/F ratio span determines the exotherm in the trap, as discussed. However, the spark advance is preferably controlled to avoid power surges and sags during the desulphation. During the lean A/F desulphation event, the spark advance is adjusted to MBT. During the rich desulphation event, the spark advance is retarded. The desulphation process is started with lean modulation, to store oxygen in the trap. After the trap's oxygen storage capacity is attained, the A/F is switch rich. During the rich half of the event, a catalytic exotherm is generated in the trap, raising its temperature. After the temperature reaches the desired temperature, say 650° C, and remains at the desired temperature for a prescribed time during which the A/F is biased rich, the desulphation event is terminated.

[0020] Referring now to Figure 4, a flowchart of the desulphation process is shown. When desox entry conditions exit as determined by the block 70, a rich flag RFLG, and timers DESOXTMR and TOTTMR are reset and the A/F is set to stoichiometric as indicated in initialisation block 72. Desox entry conditions may be based on the difference between lean to rich switching times of the upstream and downstream HEGO sensors as described in copending application FMC0769 filed, assigned to the assignee of the present invention. Other well known criteria for estimating when the trap must be purged of SO_x may also be used. At block 74 the trap temperature LNTTMP is compared with a predetermined desired desox temperature DESOXTMP of, for example, 650°C. LNTTMP may be obtained from a thermocouple or modelled. After the comparison step at block 74, the amplitude and frequency of A/F modulation is determined at block 76 based on engine speed and load and LNTTMP as input from block 78. The engine speed and load are the open loop components used in determining the modulation of the A/F necessary to arrive at the desired exotherm. The trap temperature provides a feedback component used in trimming the value of the amplitude and frequency determined from speed and load. At block 80 the desired spark timing to balance the engine torque for the respective lean and rich modulation periods is determined from previously obtained experimental data stored in look up tables. At block 82 the required number of rich cylinder events (NRCER) and lean cylinder events (NLCER) is determined based on the frequency of the A/F modulation and the engine speed. The required number of event determined at block 82 are adjusted to achieve a desired A/F of approximately stoichiometry as indicated by the rear ego signal input provided from block 84. If the trap temperature is below the desired desox temperature DESOXTMP as determined at block 86, then the rich flag RFLG is checked at block 90. The first time through this DESOX loop the flag is reset at block 72 and accordingly a lean A/F is applied to all cylinders as indicated at block 92. The spark timing is set at block 94, to the value determined at block 80, and a counter (NLCE) is incremented at block 94 to record the number of lean cylinder events that have occurred. This number is compared at block 98 with the number of lean cylinder events required (NLCER) as determined in block 82. When the events counted are equal to or greater than the number required, the rich flag RFLG is set and the counter (NLCE) is reset at block 100. Until this occurs RFLG and a counter (NRCE) for counting the number of rich cylinder events are reset at block 102 each lean cylinder event.

[0021] When the rich flag RFLG is set at block 100, a rich A/F mixture will be supplied to all cylinders the next time though the loop, as indicated at block 104. The rich spark timing value is set at block 106 and the counter NRCE is incremented at block 108 and compared at block 110 with the number of cylinder events required (NRCER). The rich flag is set at block 112 until the number of cylinder event is equal to or greater than the number required. At that time the flag RFLG and the counter NRCE are reset at block 102. Thus, when purge mode entry conditions are met, the amplitude of the A/F is modulated to raise the temperature of the trap to the desired SO_x purging temperature DESOXTMR. When the trap temperature is equal to or greater than DESOXTMP as determined at block 86, the A/F is biased to the rich side as indicated at block 88. This biasing may be accomplished by increasing the number of rich cylinder events relative to the number of lean cylinder events or otherwise supplying a relatively rich mixture to the engine over each modulation period to thereby purge the trap. This relatively rich A/F mixture is supplied for a time interval DESOXTIM. A timer DESOXTMR is incremented at block 114 each time through the loop while the trap temperature is equal to or greater than DESOXTMP, as determined at block 74, and compared with DESOXTIM at block 118. When the trap temperature has been equal to or greater than DESOXTMP for the time interval DESOXTIM the program is exited at 120.

[0022] At block 122 a check is made to determined whether the entry conditions still exists. If not the program is exited prior to expiration of DESOXTIM. If so, a timer TOTTMR is incremented each time through the loop at block 124 and compared with fixed maximum time MAXTIM at block 126. When MAXTIM is exceeded, trap damage is assumed and a diagnostic code is set at block 128 and the program is exited. The indicator lamp 66 (Figure 1) is illuminated to provide an indication that the damage code has been set.

[0023] Thus, there is described a control system design where modulation of A/F mixture supplied to the engine cylinders is provided to produce substantial exotherms in a lean NO_x trap situated downstream of a conventional TWC, thereby raising the temperature of the trap and allowing a purging of SO_x from the trap.

Claims

1. An engine control apparatus comprising
    a NO_x trap (32) located in the exhaust passage of a multi-cylinder engine(18), the NO_x trap (32) having an oxygen storage capacity;
    a catalytic converter (26) located in said exhaust passage upstream of said NO_x trap (32), the catalytic converter (26) having a lower oxygen storage capacity than said NO_x trap (32); and
    a computer (20) programmed to:

    estimate when the trap (32) should be purged, and
    decrease the A/F supplied to the engine (18) to purge said NO_x trap.

2. An engine control apparatus as claimed in claim 1, further comprising at least one exhaust gas oxygen sensor (28, 34, 36) located in said exhaust passage.

3. An engine control apparatus as claimed in claims 1 or 2, wherein said apparatus further comprises an exhaust gas oxygen sensor (28) located upstream of said catalytic converter (26) .

4. An engine control apparatus as claimed in any of the preceding claims, wherein said apparatus further comprises fuel injectors (16) which inject fuel into said multi-cylinder engine (18).

5. An engine control apparatus as claimed in any of the preceding claims, wherein said NO_x trap (32) contains a temperature sensor (42).

6. An engine control apparatus as claimed in any of claims 1 to 4, wherein said computer (20) is further programmed to estimate temperature of said NO_x trap.

7. An engine control apparatus as claimad in any of the preceding claims, wherein said catalytic converter (26) has a washcoat including cerium.

8. An engine control apparatus as claimed in any of the preceding claims, wherein said computer (20) is further programmed to adjust ignition timing during said purging of said NO_x trap (32).

9. An engine control apparatus as claimed in any of the preceding claims, further comprising a mass air flow sensor (48) positioned at an air intake of the engine (18).

10. An engine control apparatus as claimed in any of the preceding claims, wherein said purging from said trap (32) includes purging NO_x.

11. An engine control apparatus as claimed in any of the preceding claims, wherein said computer (20) is further programmed to bias toward a lean A/F after the trap is purged.

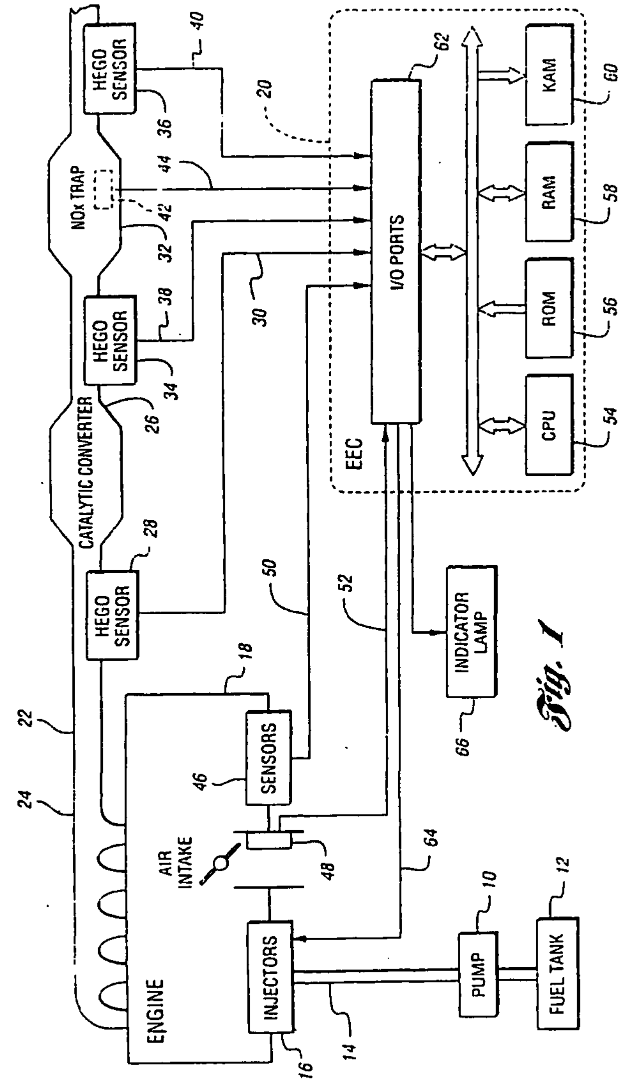

Fig. 1

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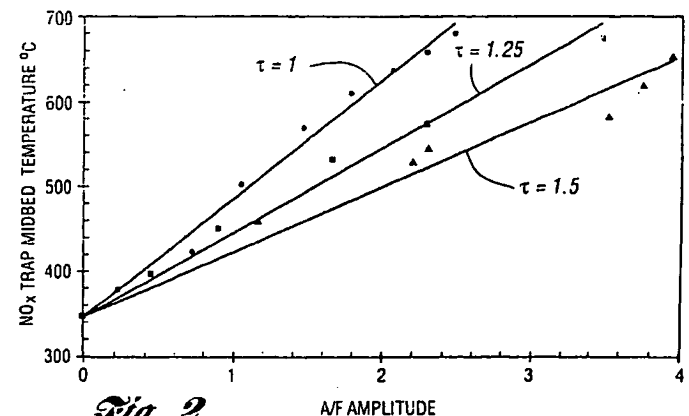

Fig. 2

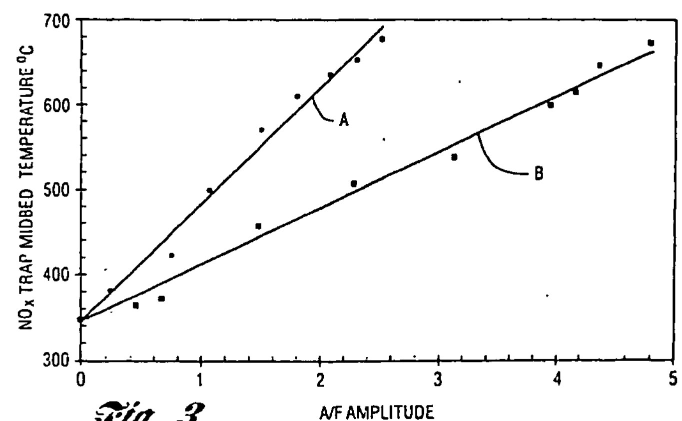

Fig. 3

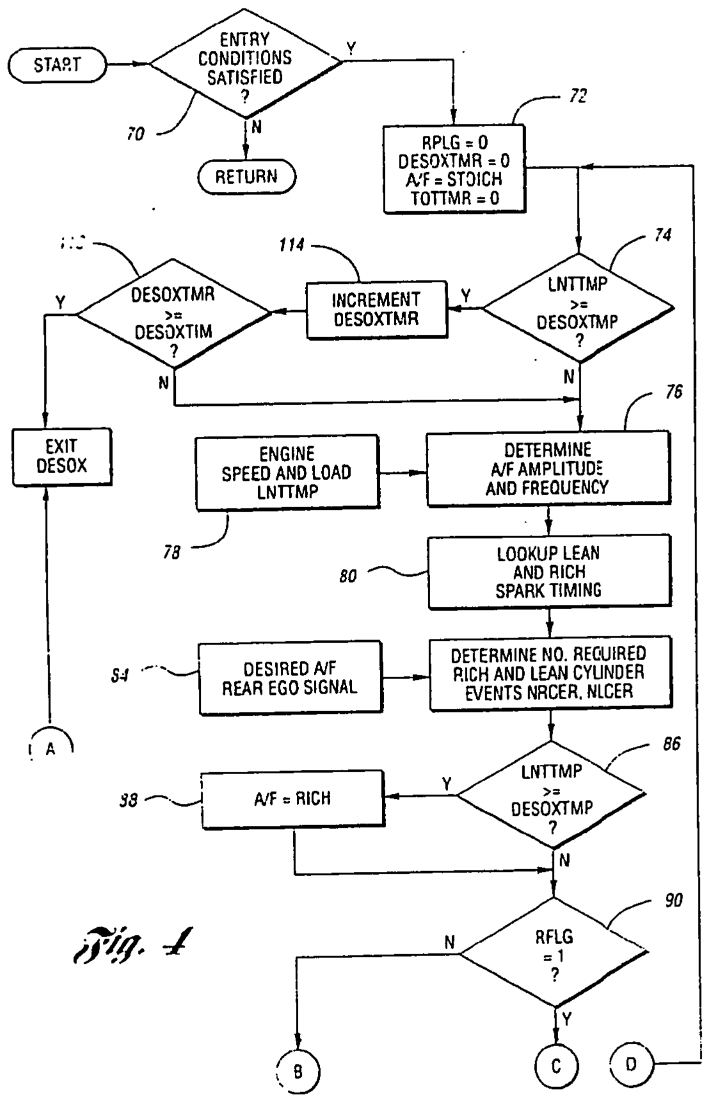
START
ENTRY CONDITIONS SATISFIED ?
Y
N
70
RETURN
72
RPLG = 0
DESOXTMR = 0
A/F = STOICH
TOTTMR = 0
74
LNTTMP >= DESOXTMP ?
Y
N
114
INCREMENT DESOXTMR
DESOXTMR >= DESOXTIM ?
Y
N
EXIT DESOX
76
DETERMINE A/F AMPLITUDE AND FREQUENCY
ENGINE SPEED AND LOAD LNTTMP
78
80
LOOKUP LEAN AND RICH SPARK TIMING
DESIRED A/F REAR EGO SIGNAL
DETERMINE NO. REQUIRED RICH AND LEAN CYLINDER EVENTS NRCER, NLCER
86
LNTTMP >= DESOXTMP ?
Y
N
88
A/F = RICH
90
RFLG = 1 ?
N
Y
A
B
C
D

Fig. 4

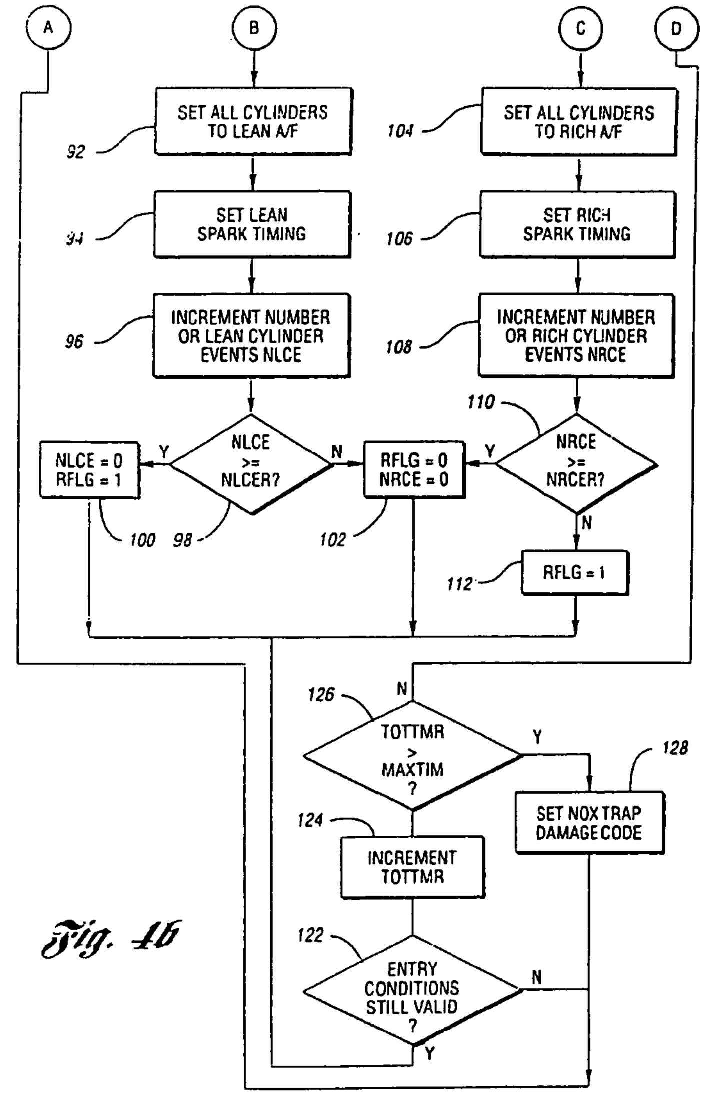
A
B
C
D
92
SET ALL CYLINDERS TO LEAN A/F
94
SET LEAN SPARK TIMING
96
INCREMENT NUMBER OR LEAN CYLINDER EVENTS NLCE
NLCE >= NLCER?
Y
N
NLCE = 0
RFLG = 1
100
98
104
SET ALL CYLINDERS TO RICH A/F
106
SET RICH SPARK TIMING
108
INCREMENT NUMBER OR RICH CYLINDER EVENTS NRCE
110
NRCE >= NRCER?
Y
N
RFLG = 0
NRCE = 0
102
112
RFLG = 1
126
TOTTMR > MAXTIM ?
N
Y
128
SET NOX TRAP DAMAGE CODE
124
INCREMENT TOTTMR
122
ENTRY CONDITIONS STILL VALID ?
N
Y

Fig. 4b